CONCRETE MADE FROM RECYCLED AGGREGATE: EXPERIENCES FROM THE BUILDING PROJECT "WALDSPIRALE"

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SUMMARY
The second building project made from concrete with recycled aggregate, the "Waldspirale" by Friedensreich Hundertwasser, was built in Darmstadt from November 1998 up to September 1999. For the production process a consistency controlled method was developed and implemented. Numerous tests during concrete production covering both freshly mixed and hardened concrete properties were evaluated. The results show, that the consistency controlled method is applicable for concrete with recycled aggregate and leads to concrete of equal quality compared to concrete made from natura! dense aggregate.

1 INTRODUCTION

For the first building project with recycled aggregate, the office building "Vilbeler Weg" in Darmstadt, the amount of water added in concrete production was constant which led to a variable workability due to variant weather conditions, unsheltered storage of all aggregate fractions and therefore different aggregate surface and core moisture. The standard deviation of the compressive strength was between 3,01 N/mm^2 and 4,23 N/mm^2. For the second building project, the "Waldspirale"' a consistency controlled production method was developed and implemented. It addresses the problems which occur when using water absorbing recycled aggregate. The goal of this production method is to reduce the standard deviation of compressive strength by maintaining a constant initial consistency for each concrete mixture while simultaneously controlling the development of rigidity, which can be higher due to the water absorption of the recycled aggregate [2].

Because the concrete mixtures used vary in terms of the amount of recycled aggregate used, an extensive testing was necessary before construction. In these tests the development of rigidity was measured and an initial consistency was fixed for each mixture. This initial consistency was the value to be reached by every concrete mixture in the concrete mixing plant. The optimization process was a big challenge for the personnel involved. The consistency of the concrete was monitored visually and using the so called ‚consistency-meter' of the mixing plant. Additionally, the consistency was measured after mixing using the flow table test.

2 PROPERTIES OF THE FRESHLY MIXED RECYCLED AGGREGATE CONCRETE

The lower dry density of recycled aggregate, when compared to natural dense aggregate, results in a higher absorptive capacity for water [2]. This aspect was be specially considered in using consistency controlled concrete production. During rainy seasons the unsheltered recycled aggregate is very damp and generally completely water saturated. During sunny periods however, the aggregate is dry and can absorb water in the first 10 to 15 minutes during and after mixing, leading to a faster development of rigidity. To prevent this negative effect, the recycled aggregate was always dampened by sprinkling water over it during dry weather periods. In addition, the amount of cement paste was increased to compensate for the consistency loss due to the rough surface of the recycled aggregate. These two alterations are necessary to produce a recycled aggregate concrete, which is equal to concrete made from natural dense aggregate regarding initial consistency, development of rigidity and compressive strength. Another positive aspect of the above alterations was a constant and substantially lower dosage of superplasticizer at the construction site since the initial consistency was mostly invariant and the development of rigidity was more predictable than during the first building project "Vilbeler Weg".

The weekly checking of the recycled aggregate quality is also of great importance. In context with consistency controlled production, the grading curve of the aggregate mix is of substantial influence.

During the construction phase of the "Waldspirale", the grading curve of all aggregate fractions remained within tolerable boundaries.
During construction, all concrete mixtures in use were tested. In this paper, only representative mixtures are shown. These were the two mixtures mostly in use:

- Concrete sort 590321 (B 25), the concrete for the foundations. Initial consistency was set to 36-38 cm in flow table value
- Concrete sort 540423 (B 25), the concrete for all walls, ceilings, pillars, etc... Initial consistency was set to 40-42 cm in flow table value

Both mixtures were designed by the guideline of the ‚Deutscher Ausschuss für Stahlbeton' [1] and are displayed in Table 1.

Table 1: Main concrete Mixtures

Concrete Sort	540423	590321
Compressive strength class	B25	B25
Water [kg/m^3]	190	180
CEM I 42,5 R [kg/m^3]	-	290
CEM III/A 32,5 R [kg/m^3]	300	-
Fly ash	50	40
Effective water-cement ratio[-]	0,59	0,59
Sand 0/2a [kg/m^3]	616	615
Aggregate 2/8 [kg/m^3]	530	290
Recycled aggregate 8/16 [kg/m^3]	569	334
Aggregate 16/32 [kg/m^3]	-	544
Water reducing agent [kg/m^3]	1,5	-
Initial consistency a_{10min} [cm]	40-42	36-38

Viewing the results of the 10 minute and 45 minute flow table tests (Table 2) it is obvious, that the consistency control method is applicable after a short optimization and acclimatization phase when starting the concrete production. All concrete mixtures were produced with the initial consistency set during the first laboratory tests (when comparing the mean value to the postulated a_{10min}). Concrete sort 540423 was initially produced slightly stiffer (a_{10min} = 38 cm; until 19th of January 1999) for safety reasons but then adjusted to a_{10min} = 42 cm when it was obvious that the concrete mixture would easily reach the estimated compressive strength, thus improving workability and reducing the superplasticizer dosage on site. Sort 540423 was specially designed for winter construction and fast stripping, the main reason for the high compressive strength (postulated f_s=40N/mm).

The standard deviation of the flow table test value between 2,0 cm and 3,4 cm shows, that the consistency was held relatively constant during the whole construction period. The development of rigidity ($a = a_{10min} - a_{45min}$) is the same, as in the production of concrete with natural dense aggregate.

Table 2: Results of the consistency tests

Concrete Sort	540423 until 19.1.99	540423 after 21.1.99	590321
Postulated a_{10min} [cm]	38-40	40-42	36-38
a_{10min} [cm]			
Meanvalue	38,3	41,2	36,3
Standard deviation	3	3,5	3,4
$a_{45minutes}$ [cm]			
Meanvalue	34,1	35,7	33,7
Standard deviation	2,1	2,9	3,2
Difference Δa [cm]	4,2	5,5	2,6

The average development of rigidity lies between 2,6 cm and 5,5 cm. The concrete mixtures produced with a stiffer initial consistency show a lower development of rigidity. The data collected from concrete sort 540423 shows the influence of a change in initial consistency: raising initial consistency from 38 cm to 42 cm increased the mean value for development of rigidity (a) from 4,2 cm to 5,5 cm.

3 PROPERTIES OF THE HARDENED RECYCLED AGGREGATE CONCRETE

The results of the compressive strength at the mixing plant tests show (Table 3), that all concrete sorts reach their destined class or even turn out better than expected. Since concrete sort 540423 was redefined during construction, the results before and after the redefinition were evaluated separately. The mean value for compressive strength of 52,34 N/mm^2 was much higher than needed, therefore it was decided to increase workability by adding more water to the mixture. This reduced the mean value to 42,29 N/mm^2. The values of the construction site test cubes were similar, 49,78 N/mm^2 before and 41,33 N/mm^2 after changing the initial consistency. The standard deviation of compressive strength is in an acceptable area, but is larger for concrete sort 540423 due to the fact, that often only very small amounts (approximately 10 m^3) were produced during one day. The sort 590321 was used for the foundations and was produced in greater daily amounts, therefore making it easier to optimize the consistency control method. This resulted in a smaller standard deviation of compressive strength compared to all other mixtures in use (Table 3).

Table 3: Results of the compressive strength tests

Concrete sort	540423 until 19.1.99	540423 after 21.1.99	590321
Postulated f_s [N/mm^2]	40	40	30
Mixing plant			
Mean value [N/mm^2]	52,34	42,29	34,23
Standard deviation [N/mm^2]	4,35	4,44	2,44
Amount of cubes tested	69	213	57
On site			
Mean value [N/mm^2]	49,04	40,75	36,87
Standard deviation [N/mm^2]	5,28	4,36	3,53
Amount of cubes tested	66	196	51

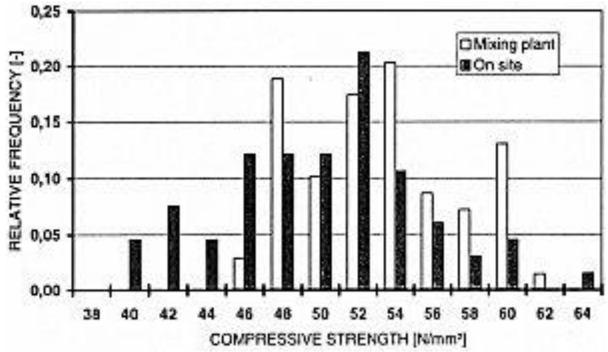

Fig. 1a: Histogramm of compressive strength, 540423 until 19.1.1999

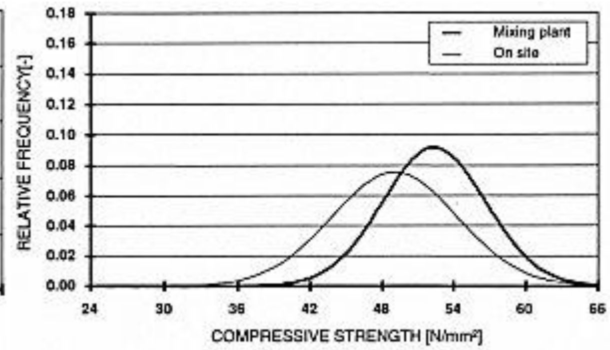

Fig 1b: Gaussian distribution of compressive strength, 540423 until 19.1.1999

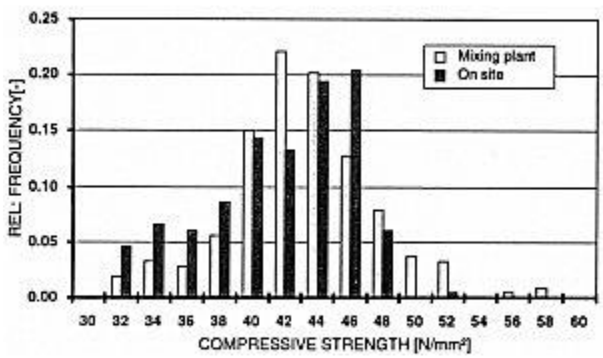

Fig 2a: Histogramm of compressive strength, 540423 after 21.1.1999

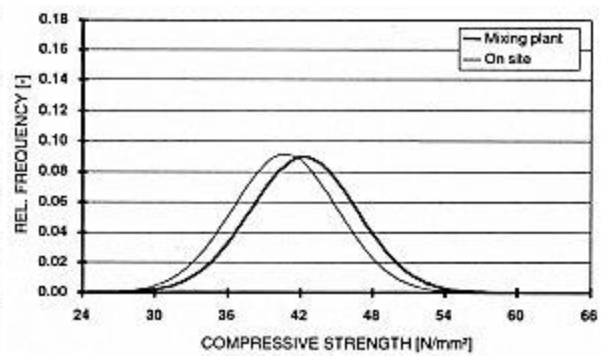

Fig 2b: Gaussian distribution of compressive strength, 540423 after 21.1.1999

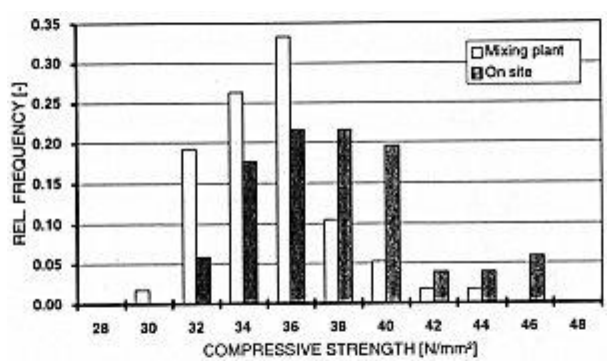

Fig 3a: Histogramm of compressive strength, 590321

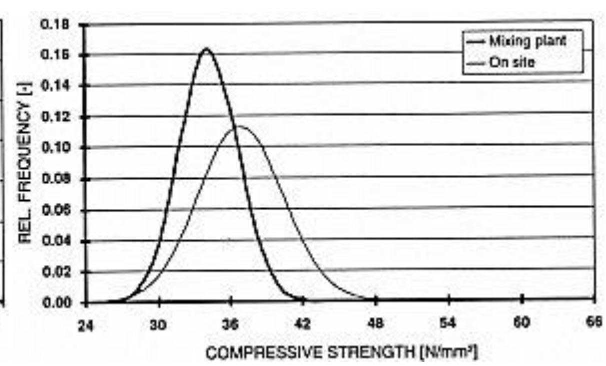

Fig 3b: Gaussian distribution of compressive strength, 590321

In general it is always of advantage to produce larger amounts of each concrete sort per day, as it was the case with sort 590321. Since the mixing plant produced concrete for one construction site only (namely the "Waldspirale"), the amounts of concrete called for only exceeded 200 m^3/day during the concreting of the foundations. This is not realistic, as a regular mixing plant serves for more than one construction site. It is therefore obvious, that the optimization process will be of even greater success in industrial scale production.

4 CONCLUSION

Concrete made with recycled aggregate can be used in many areas up to compressive strength class B 35 according to the DAfStb guideline [1]. After applying the mentioned two measures in the production process, concrete with recycled aggregate shows no relevant difference to concrete made from natural dense aggregate and can be casted or pumped just like a standard concrete mixture. The addition of superplasticizer before dasting is only necessary, if the concrete is produced with a stiffer consistency as demanded by the contractor on site, as it was the case with the "Waldspirale". The reason for this was to minimize hydration temperature by limiting the amount of cement paste and gaining workability with superplasticizer. For building members which are not susceptible to hydration temperature development, the necessary workability consistency can be achieved by controlling development of rigidity (by dampening the recycled aggregate) and initial consistency (by indreasing the amount of dement paste) alone.

References

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